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A marker-based watershed method for X-ray image segmentation

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ABSTRACT

Digital X-ray images are the most frequent modality for both screening and diagnosis in hospitals. To facilitate subsequent analysis such as quantification and computer aided diagnosis (CAD), it is desirable to exclude image background. A marker-based watershed segmentation method was proposed to segment background of X-ray images. The method consisted of six modules: image preprocessing, gradient computation, marker extraction, watershed segmentation from markers, region merging and background extraction. One hundred clinical direct radiograph X-ray images were used to validate the method. Manual thresholding and multiscale gradient based watershed method were implemented for comparison. The proposed method yielded a dice coefficient of 0.964 ± 0.069, which was better than that of the manual thresholding (0.937 ± 0.119) and that of multiscale gradient based watershed method (0.942 ± 0.098). Special means were adopted to decrease the computational cost, including getting rid of few pixels with highest grayscale via percentile, calculation of gradient magnitude through simple operations, decreasing the number of markers by appropriate thresholding, and merging regions based on simple grayscale statistics. As a result, the processing time was at most 6 s even for a 3072×3072 image on a Pentium 4 PC with 2.4 GHz CPU (4 cores) and 2G RAM, which was more than one time faster than that of the multiscale gradient based watershed method. The proposed method could be a potential tool for diagnosis and quantification of X-ray images.

1. Introduction

With the development of medical equipment and computer technologies, computer aided diagnosis (CAD) [1–4] has shown great clinical value and become a research spot in the area of modern medical imaging. It makes use of medical images to extract tissues of interest for diagnosis to relieve burden of medical experts and augment diagnosis. With the invention of direct radiographs (DR) to have a spatial resolution being comparable to or even better than computed tomography images (as high as 0.14 mm) and good contrast, its value in screening and diagnosis is increasingly recognized [5]. With the increased availability and spatial resolution of DR images, more skills and more manpower are needed to interpret the DR images. Due to complexity and variability of DR imaging, DR

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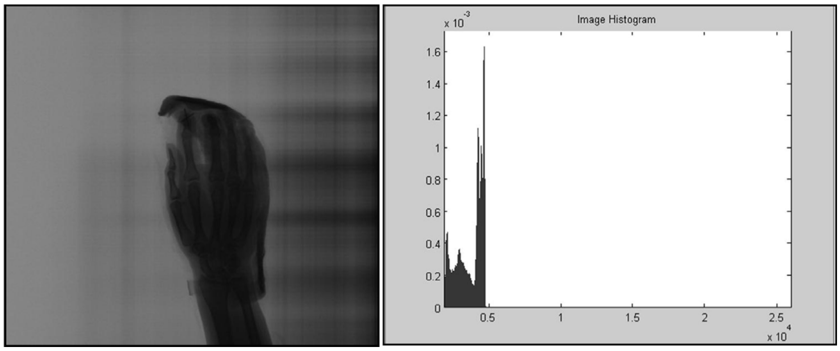

Fig. 1 – An X-ray image that could not be segmented with grayscale thresholding.

images may have very complicated background. For example, the background can have complicated shape and complicated grayscale distribution such as the case of variable grayscales that overlap with those of foreground. Removing background could facilitate subsequent steps of CAD, which is the focus of this paper.

Though there are efforts on segmentation with some sort of user intervention [6–9], automatic segmentation is preferred in real applications.

Grayscale thresholding is to classify a pixel according to its grayscale by comparing with a threshold or thresholds. The threshold could be determined using or without using prior knowledge [10]. Global thresholding could work well in two typical scenarios: background grayscales do not overlap with those of foreground [11], or those foreground and background pixels have overlapping grayscales but are disjointed in space. It fails otherwise. Fig. 1 shows an X-ray image that could not be segmented well with global thresholding (the segmentation result with threshold manually set is shown in Fig. 10b).

Another widely used automatic method is watershed segmentation [12,13]. It regards grayscale image as a topographic relief with every local minimum and its adjacent pixels forming a catchment basin. Watershed is formed to prevent merging of adjacent basins. Usually gradient images are used as input of watershed-based segmentation. Watershed segmentation in its original form has a good response to weak edges but will yield over-segmentation as each local minimum will form a catchment basin. There are efforts to handle the over-segmentation. Wang [14] proposed a multi-scale gradient algorithm to decrease the number of local minimums and morphological reconstruction to eliminate small local minimums caused by noise or quantization. Chen and co-workers [15] utilized an anisotropic diffusion filtering to remove image noise before computing gradient using multi-scale morphological gradient operators. These two methods aimed to decrease number of local minimums through multi-scale morphological gradient operators. However the scale range depends heavily on image edge width and is hard to determine. Large scale range will increase the computational cost while small scale range may lose some edge information. Marker-based watershed segmentation is another way to prevent over-segmentation. It directly makes use of image markers as the catchment basins without extracting image local minimums. How to determine markers remains a key issue. Manually selecting markers on image is one way in some easy situations. But they need to be determined automatically in most real problems. Rodríguez et al. [16] proposed to obtain markers for blood vessels segmentation based on local grayscale standard deviation. This method might not be easily extended for non-vessel images.

In this paper, a marker-based watershed segmentation method is proposed to segment DR images. The method has been validated on one hundred clinical DR images and compared with manual thresholding and multiscale gradient based watershed method [9].

2. Materials and methods

2.1. Materials

Altogether 100 DR images of different human body parts including 34 chests, 33 hands and 33 legs were obtained from the Beijing Aerospace Zhongxing Medical Systems Co. Ltd. These images were produced using three kinds of DR systems with different pixel sizes of 0.14 mm, 0.15 mm, and 0.40 mm, respectively. The image dimensions ranged from 1024×1024 to 3072×3072. The images were 16 bits with a grayscale range from 0 to 65,536. The background had greater average grayscale than the foreground (which is the tissue to be imaged such as hand). Fig. 2 showed respectively typical images of the hand, chest and leg, and their corresponding histograms with percentiles.

2.2. Methods

The proposed algorithm consists of 6 modules (Fig. 3): image preprocessing to eliminate the influence of very few pixels with highest grayscales, calculation of gradient magnitude with a simple gradient operator, determination of seed pixels based on thresholding of gradient magnitudes, watershed segmentation from markers, region merging, and derivation of background through grayscale thresholding. Details are described below.

2.2.1. *Image preprocessing*

The purpose of preprocessing is twofold: noise removal while preserving edges, and highlighting grayscales that are of